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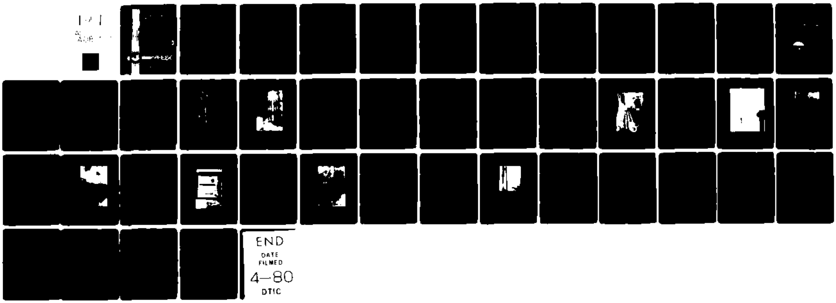

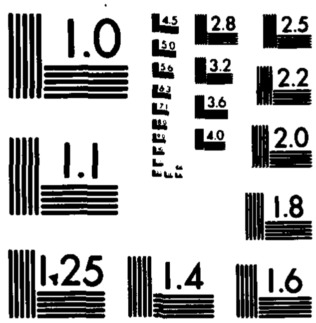

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ESL-TR-79-36

FREEZE PROTECTION FOR IMPRESSED-CURRENT, CATHODIC-PROTECTION ANODES IN WATER STORAGE TANKS

LEVEL II

MAJ ROGER J. GIRARD
DR JAMES R. MEYERS
ENGINEERING RESEARCH DIVISION

DECEMBER 1979

FINAL REPORT
JANUARY 1976 - DECEMBER 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A technique was developed for supporting anode assemblies from the bottom of water storage tanks using polyester-type, fiberglass vertical columns. The columns were readily fabricated from the lightweight, non-metallic material; button-type anodes were easily positioned on the columns. The columns were supported in the tank by steel bases welded to the tank bottom. This was a unique departure from convention; impressed-current type anode assemblies are conventionally suspended from the roof of the tank using techniques which subject them to damage during the winter (i.e., icing conditions).

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20. ABSTRACT(Concluded)

It was established that the non-metallic, bottom-supported anode system was a viable approach for supporting anode assemblies in water-storage tanks. Where severe icing occurs, horizontal supports should not be connected between the columns and the tank wall. Equally important, it was found that header cables to the anodes and permanent reference electrode assemblies could be effectively protected from ice damage by encasing them in polyvinyl chloride conduit anchored to the tank surface.

PREFACE

This report was prepared for the Air Force Engineering and Services Center (AFESC), Engineering and Services Laboratory under Job Order Number 21024004 for freeze protection of impressed current, cathodic protection systems inside water storage tanks. The field and laboratory work was accomplished in-house by AFESC personnel while the final analysis of test data and actual report preparation was completed by Dr. Meyers of the School of Civil Engineering, Air Force Institute of Technology. The basic concept for this new prototype cathodic protection system was provided by Air Force Civil Engineering Center Engineering Report 75-6 dated April 1975.

This report is designed for use by base and Command Corrosion Engineers to enhance their understanding of freeze damage to cathodic protection systems inside water storage tanks and to provide lessons learned on operation of a system designed to avoid freeze damage.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS), where it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

The Problem

Air Force personnel have recognized for many years that freezing temperatures in northern regions make it extremely difficult to maintain impressed-current type cathodic protection systems in unheated water storage tanks. Excluding the riser area of these tanks, ice formation produced unacceptable stresses on conventionally installed anode assemblies causing them to become electrically disconnected and physically removed from their intended position.

Various approaches have been used to mitigate the problem, including the suspension of durable, long-life expectancy anodes (e.g., high-silicon chromium-bearing cast iron anodes) from the tank roof using resilient nylon rope. More commonly, the problem has been solved by the annual installation of expendable aluminum anodes. Unfortunately, neither of these approaches represents the most desirable situation. Limited success has been achieved using the nylon rope concept; however, it is vulnerable to destruction when unusually thick formations of ice develop inside the tank. The annual replacement of aluminum anodes is undesirable because of the increasing unavailability and cost of both materials and maintenance personnel.

Since a reliable, commercially-available, long-life expectancy anode system did not exist, it was considered important to develop a system which would successfully endure a wide variety of icing conditions. The development of such a system would be expected to be extremely cost effective in maintaining the continuous corrosion control required to prevent red-water complaints and the eventual electro-chemical destruction of expensive water-storage facilities.

SECTION II

PRELIMINARY SYSTEM DESIGN

Conceptual Studies

A number of conceptual anode-installation designs were initially considered. These included the use of floating anode assemblies, the suspension of anode assemblies from spring-loaded reels/floats that would permit the anodes to rise and fall with the water level, and the use of fixed supports/columns attached to the bottom of the tank bowl.

A variety of engineering and economical problems suggested that the use of floats and/or cable retractors was not a viable solution to the problem. For example, cable retractors are expensive and appear to be technically unfeasible; floating assemblies would tend to be relatively unrestrained which could permit the anodes to short-circuit with the cathodic tank.

Based upon the limited knowledge which exists on the nucleation and growth of ice inside a water storage tank, it appeared that the most feasible solution to the problem would be a design where the anodes are supported by vertical columns anchored to the bottom of the tank. The header cables to these anodes would be introduced to these columns from the bottom of the tank, avoiding their exposure to the fluctuating ice/water zone. It was believed that the installation of a bottom-supported anode system would be capable of maintaining structural integrity under even the most adverse icing conditions (e.g., when as much as 3 feet of ice formed in the top, along the wall, and on the bottom of the tank).

Further considerations suggested that conventionally used, long strings of short-length anodes and fragile, long-length anodes should be avoided in the design of the system. The most promising approach appeared to be the attachment of button-type long-life expectancy anodes to the exterior surface of the vertical supports/columns. This concept would eliminate the exposure of relatively-fragile header cable to the conditions which could cause it to be mechanically destroyed by the ice.

It was also believed that the vertical supports should be fabricated from a lightweight, non-metallic material. This would facilitate fabrication/installation and eliminate the necessity to cathodically protect additional metal inside the tank. Further, massive steel columns could possibly adversely affect the structural integrity of the tank bottom such as might occur during certain severe icing conditions.

These criteria and considerations culminated in the selection of polyester-type, fiberglass reinforced (FRP) material for the vertical columns and high-silicon chromium-bearing cast iron (HSCBCI) button-type anodes. This was considered to be a logical selection of materials since adaptable polyester-type, fiberglass shapes and HSCBCI button-type anodes are commercially available.

Fabrication of the Laboratory Test Column

The feasibility of using this new anode concept for cathodically protecting water storage tanks was investigated during a small-scale laboratory study. Basically, the laboratory study was designed to develop an optimum technique for attaching the button-type anodes to the polyester-type, fiberglass column. For this study, 4-inch by 4-inch by 0.25-inch (square tube) sections of polyester-type, fiberglass (EXTERN 500®) were obtained from the Morrison Molded Fiber Glass Company, Bristol, Virginia. Sixteen-pound, Durichlor 51® (nominally, by weight: 14.5% Si, 0.75% Mn, 0.95% C, 4.5% Cr, balance Fe), button-type anodes (Durco K-6 anodes) were obtained from The Duricon Company, Dayton, Ohio.

It was found that the fiberglass could be readily fabricated to accept the anodes. Holes could be easily drilled in one face of the fiberglass through which the threaded studs in the backs of the anodes could be inserted and bolted in place. Further, it was observed that the fiberglass could be adhesively bonded to itself. The latter was considered important since it was desired to ultimately seal the various openings in the column (e.g., the 2.5-inch diameter holes in the back face of the column which were used to bolt the anodes to the column and make electrical connections of the header cable to the anodes). The ease of adhesive bonding was also desirable if it was found necessary to laterally support the columns to the tank wall in an actual field installation.

The initial laboratory anode column was readily assembled using conventional techniques. The two-anode configuration used is described in Figure 1. Basically, the anodes were positioned 2 feet apart on one surface of the column. In order to seal the back faces of the anodes and protect the anode studs from unacceptable anodic current discharge, one anode back face was coated with a coal-tar mastic; the anode was bolted in place while the mastic was still tacky. A rubber sealant was applied to the back face of the other anode. This provided a means of evaluting two potential sealing materials. The anodes were electrically connected inside the column using pre-cut, No. 8/7-strand copper, high molecular weight (HMPE) cable. After bolting the header cable to the anode studs, these exposed-metal areas were initially not protected since it was believed that the ultimate assembly would be watertight. Further, sealing the exposed

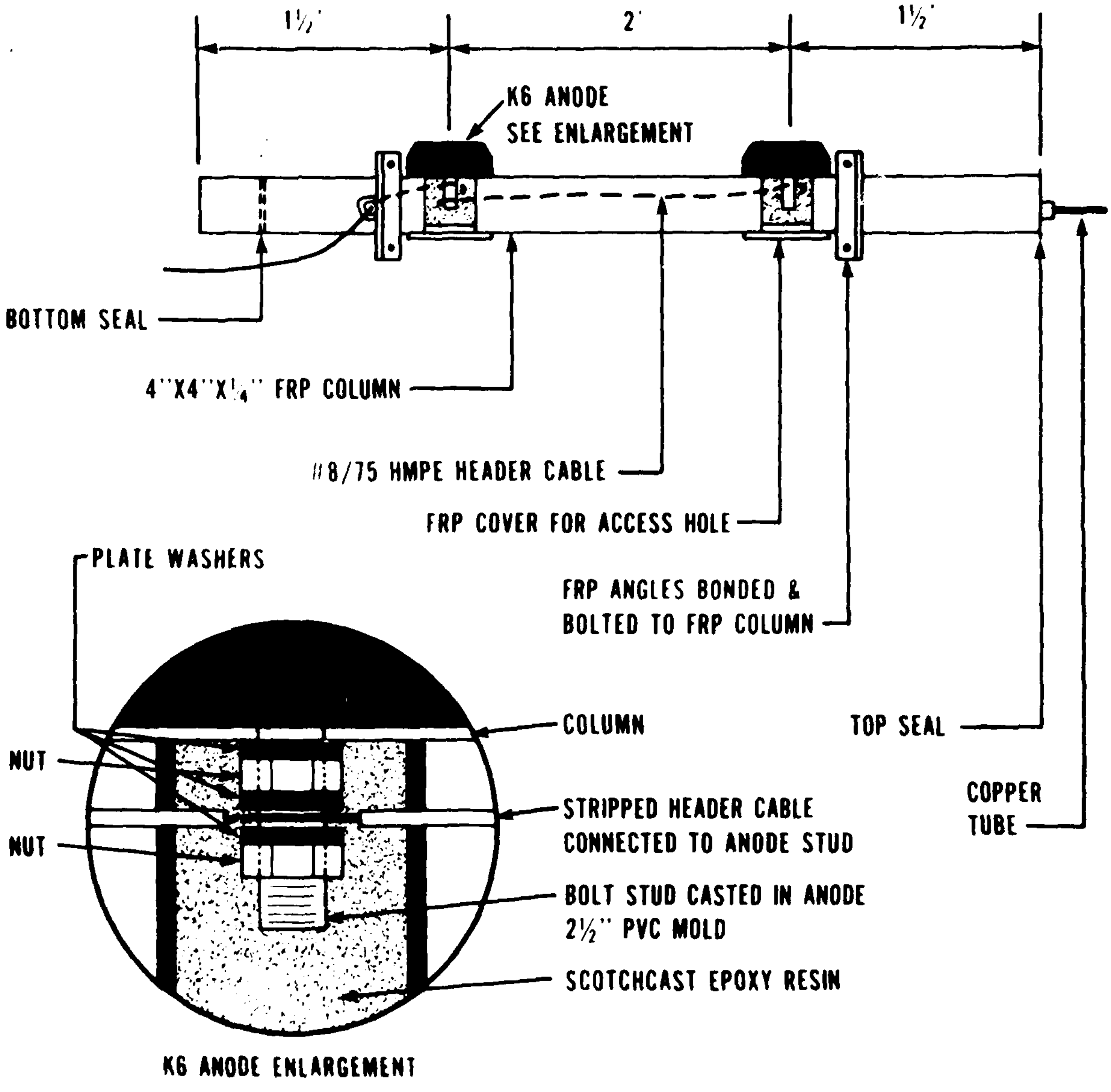

Figure 1. Laboratory Test Assembly Used to Evaluate the Feasibility of Installing Button-Type High-Silicon Chromium-Bearing Cast Iron Anodes on a Polyester-Type, Fiberglass Square Tube

bolts, wire, and studs would make anode replacement somewhat difficult, if not impossible.

In addition to attaching the two anodes to the column, four 2-inch by 2-inch by 0.25-inch polyester-type, fiberglass angles were adhesively bonded (using EPI-Seal, Spec 10-10) to the experimental column (Figure 1); the angles were held in place during the adhesive curing cycle with bolts. This established the feasibility of laterally supporting the column if it became necessary during field application.

For this installation, both coal tar mastic-coated and uncoated bolts/nuts were used since these metals would be exposed to stray-current corrosion.

Subsequently, the access holes, the top and bottom of the column, and the connector insert used to introduce the header cable into the column were sealed using fiberglass plates and/or EPI-Seal, Spec 10-10, adhesive in an effort to make the assembly watertight. A copper tube was introduced into the top of the column in order to evaluate the integrity of the sealed joints (i.e., the watertightness of the assembly).

Evaluation of the Laboratory Test Column

The initial test column was submerged in a galvanized-steel reservoir which contained 330 gallons of 2,200 ohm-cm water. Pressurization of the column using 15 pounds per square inch (psi) air revealed that the system would not successfully pass this test. Air bubbles formed along the surface and ends of the sealed column. Further investigation revealed that the polyester-type fiberglass material was resin-poor; microscopic voids existed in the material. Attempts to seal these voids were unsuccessful. Since the column would be exposed to approximately 11 psi of water pressure during a typical field installation, the pressure test established that the column would be expected to fill with water. This was undesirable since calculations revealed that the unprotected metals (studs, nuts, and wire) inside the column would be exposed to unacceptable amounts of anodic current discharge.

A number of methods were considered for protecting the metals inside the column. The most viable and cost effective of these was determined to be the complete sealing of each connection between the anode and the header cable. Unfortunately, this decreased the operational flexibility of the system. Complete sealing eliminated the option of replacing individual anodes. If one anode on a multiple-anode column failed, the entire column would have to be replaced.

Subsequent tests revealed that the studs, nuts, and wire inside the column at each anode could be effectively isolated from the environment by casting a small volume of SCOTCH-Cast® Epoxy around each connection, using an expendable polyvinyl chloride (PVC) coupling as a mold. An anode assembly using this revised technique for protecting the exposed metal inside the column was subsequently tested under applied anodic current conditions such as might be expected in an actual installation.

For this test, the assembled column was submerged in 2,200 ohm-cm water using the galvanized-steel reservoir, and the anodes were positioned to face the bottom of the tank. Each anode was approximately 14 inches from the bottom, 18 inches from the sides, and 36 inches from the ends of the rectangular-shaped reservoir. The system was energized using a direct current (DC) power supply (rectifier) at 36 volts and 2 amperes in order to obtain a 1-ampere discharge from each anode (i.e., at an anodic current density of 2 amperes per square foot). This rigorous test represented a current discharge of four times that recommended by the anode manufacturer. The current was maintained at 2 amperes throughout the three months of laboratory testing.

Results of this test revealed that both the coal tar mastic and rubber sealant used to seal the back faces and studs of the anodes appeared to have been prematurely aged. The EPI-Seal, Spec 10-10, did not exhibit these undesirable behaviors. This suggested that EPI-Seal, Spec 10-10, would be a desirable material for protecting the back faces and studs of the button-type anodes. It was also observed that the uncoated and coal tar mastic coated bolts/nuts used to support the polyester-type fiberglass angles to the column during the curing cycle of the adhesive were equally attacked by stray-current corrosion. This suggested that there would be no advantage to coating the expendable bolts/nuts in an actual field installation. Examination of the anodes revealed that uniform anodic current discharge had occurred even at the high current density selected for the study. Basically, the laboratory study provided significant insight with regard to designing an actual field installation.

SECTION III

DESIGN OF AN ACTUAL SYSTEM

Selection of the Tank

Approximately 20 Air Force Bases are located in areas where severe winter weather commonly causes ice damage to the anode assemblies used in the cathodic protection of water storage tanks. Additional facilities are located in areas of mild-to-severe winter weather where occasional freeze damage to anode assemblies can be expected to occur (Figure 2). Examination of the weather conditions and tanks available for cathodic protection established that Selfridge Air National Guard Base (ANGB), Michigan, would be an ideal location for the full-scale test. Winters at Selfridge are generally severe, the water is relatively corrosive to steel, a relatively small (100,000-gallon) water storage tank was available for the initial installation, and the water in the tank is usually stagnant during winter months. Further, the tank required cathodic protection because a system installed earlier had failed due to ice damage of the nylon rope-supported anode assemblies which had been suspended from the roof of the tank.

Further justification for the selection of this tank was knowledge that an operational rectifier (30 VCD - 12 A output) was already installed which could be adapted to the new system. The tank could also be taken out of service for the time period which might be required to develop optimum techniques for expeditiously installing the bottom-supported columns.

Description of the Tank

The welded-steel, 100,000-gallon, double-ellipsoidal tank (Figure 3) was constructed by Chicago Bridge and Iron Company in 1958. Basically, the structure is approximately 117.5 feet high and has a 5-foot deep pit at its base. The distance between the bottom of the pit and the bottom of the bowl is approximately 96.5 feet; the high and low water levels inside the tank are, respectively, approximately 26 and 15 feet above the bottom of the bowl. Segmented, the heights of the wetted bottom, center, and top sections of the tank are, respectively, 7, 14, and 5 feet. The diameter of the tank at its widest point (i.e., the center section) is 28 feet; the diameter of the riser is 5 feet.

Since the tank was not available for inspection, there was no means of evaluating the quality or efficiency of the coating which reportedly existed inside the tank. The only information available was that in 1967 the tank had been sand blasted to a near-white metal finish (i.e., to Steel Structures Painting

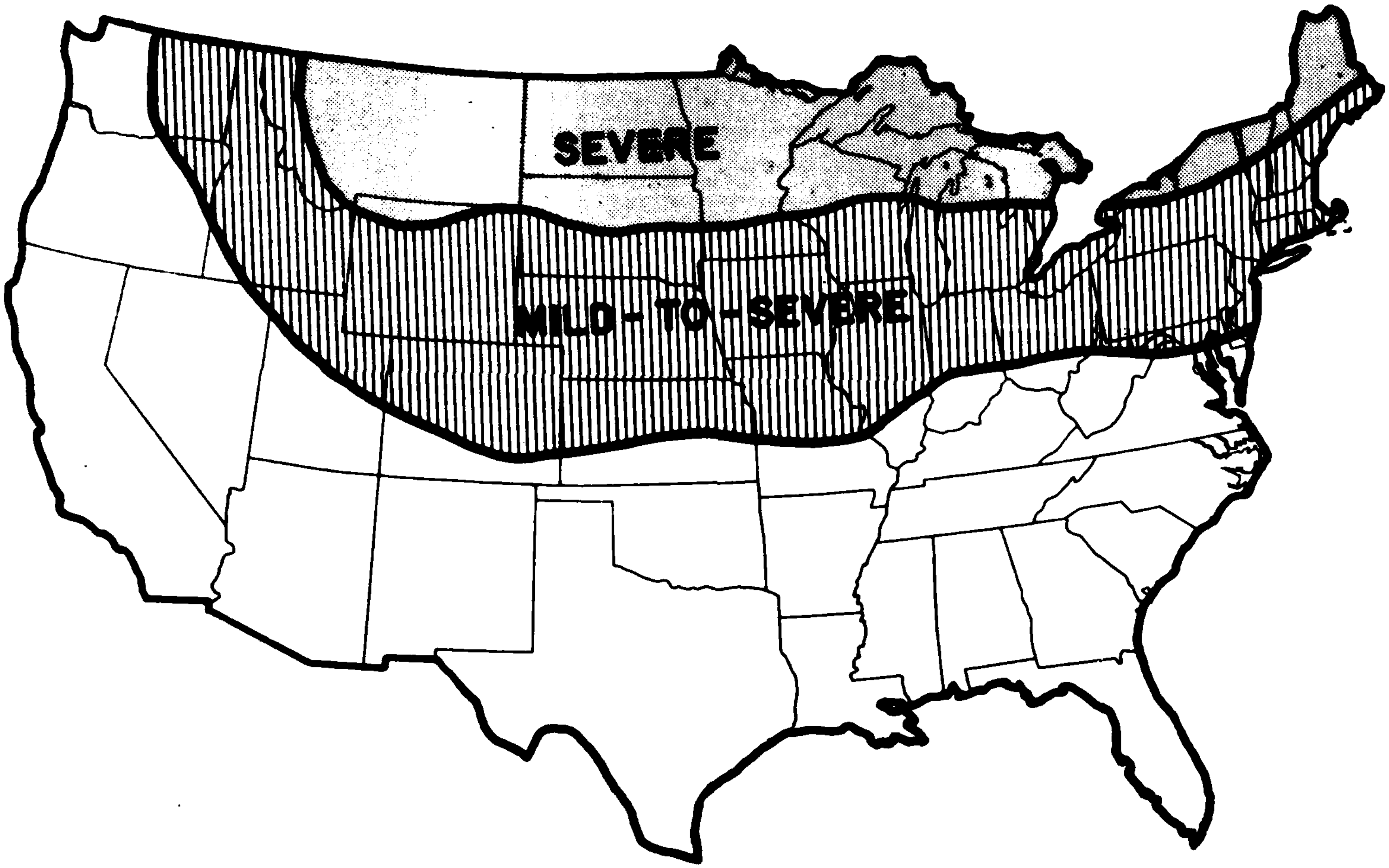

Figure 2. Areas Where Severe and Mild-to-Severe Icing Conditions Can Be Expected in Unheated Water Storage Tanks Located in the CONUS

Figure 3. General View of Steel, 100,000-Gallon, Double-Ellipsoidal Water Storage Tank at Selfridge Air National Guard Base

Council Specification SSPC-SP 10-63) and coated with a four-coat high-solids vinyl finish which conformed to American Water Works Specification AWWA D102-62, Paint System No. 4.

Cathodic Protection Design

The basic cathodic protection system design for the Selfridge ANGB water storage tank was accomplished using existing technology (Reference 1). Briefly, the design was based upon: (1) a desired 10-year life expectancy for the cathodic protection system; (2) a conservative current density requirement of 5 ma/ft^2 of base surface area*; (3) a water resistivity of 5,000 ohm-cm; (4) an anode consumption rate of 1 lb/amp-yr; (5) a coating efficiency of 50 percent; and (6) an anode efficiency of 50 percent. The design calculations are included in Appendix A. In these calculations, it should be noted that protection for the riser was included in the system design. This was not a basic part of the present investigation since freezing in the riser is generally not a significant problem; conventional, flexible-anode assemblies with continuous cable can be used to protect this section of the tank.

The design calculations suggested that approximately 1322 ft^2 of uncoated steel would require protection in the bowl of the tank. This corresponded to a total cathodic current requirement of 6.6 amperes and the need for approximately 132 pounds of HSCBCI anode material in order to achieve the desired cathodic protection system life expectancy of 10 years.

Further calculations revealed that 8 main anode columns would be required to protect the wall of the tank; these should be located equidistant around the tank on a 10-foot radius from the center of the tank (i.e., 4 feet from the tank wall). The desire to achieve uniform distribution of the current and simultaneously protect a significant portion of the tank bottom culminated in the decision to use four Durco Type K-6®, button-type, HSCBCI anodes on each of the 8 main columns. Using this arrangement, it was found that only two additional (stub-type) anodes would be required to protect the remaining area on the bottom of the tank. The stub-type anodes would be located 3.3 feet from the center of the bowl. With a total of 36 anodes, the anodic current discharge would be approximately 0.37 amp/ft^2 (well below the recommended current output limitation recommended by the manufacturer).

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* In practice, well over 98 percent of the cold water storage tanks encountered can be protected by a maximum design-current density of 2.5 ma/cm^2 (Reference 2).

The location of the main anode columns and the stub-type anodes are shown in Figures 4 and 5. The overall height of the main anode columns was limited to 12.5 feet in order to stay below the low-water level in the tank. The bottom anode on each column was positioned 5 feet above the tank bottom in order to maintain a constant 4-foot separation between the side wall and the sloping tank bottom; the remaining three anodes on each main column were equally spaced at 2-foot intervals from the bottom anode (i.e., the top anode on each main column was located 11 feet above the tank bottom). The two stub-type anodes were positioned 5 feet above the tank bottom in order to provide adequate protection for the miscellaneous steel structures which existed in the vicinity of the riser.

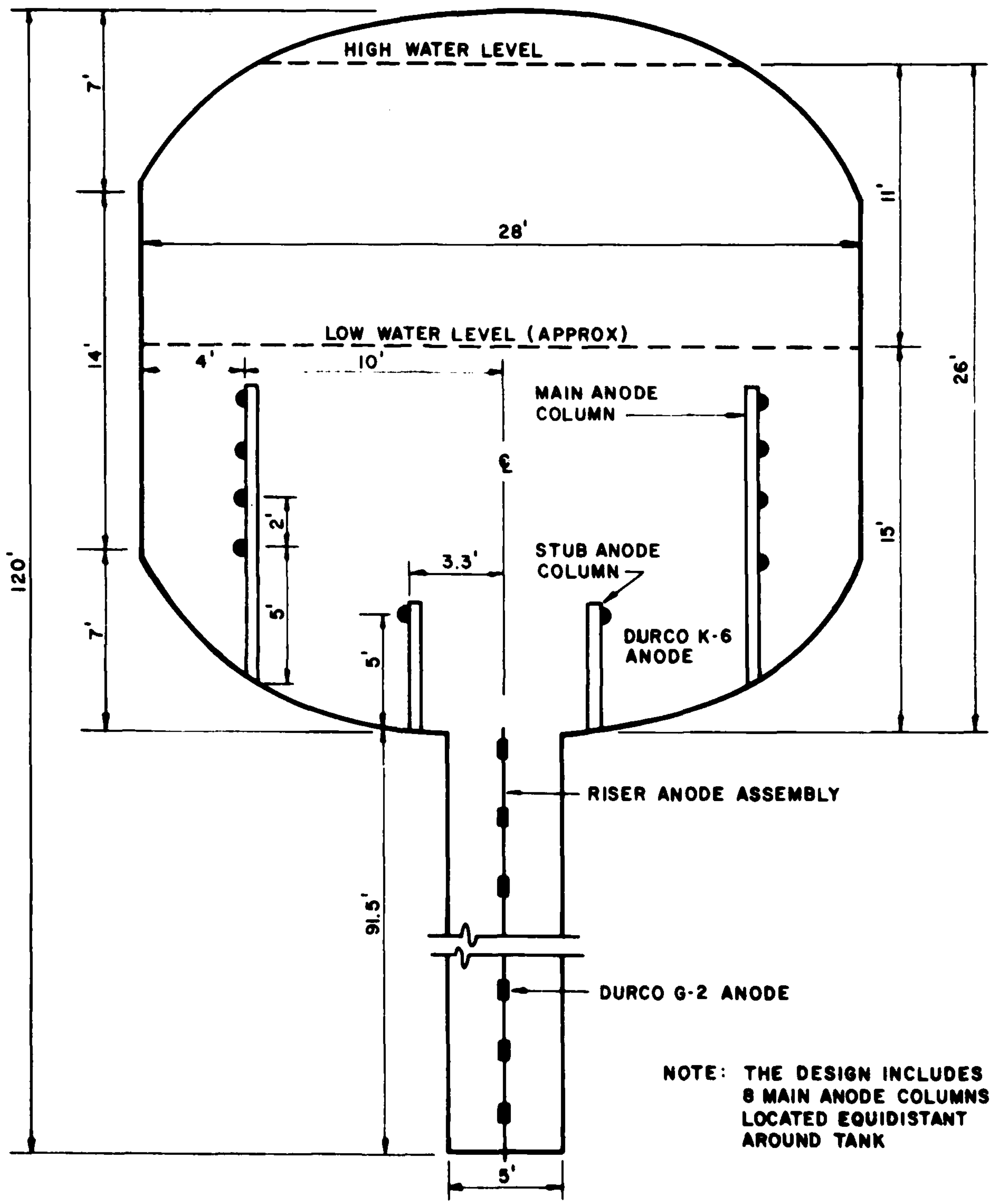

Figure 4. Side View of 100,000-Gallon Water Storage Tank at Selfridge Air National Guard Base Showing the Location of Anodes for the Cathodic Protection System

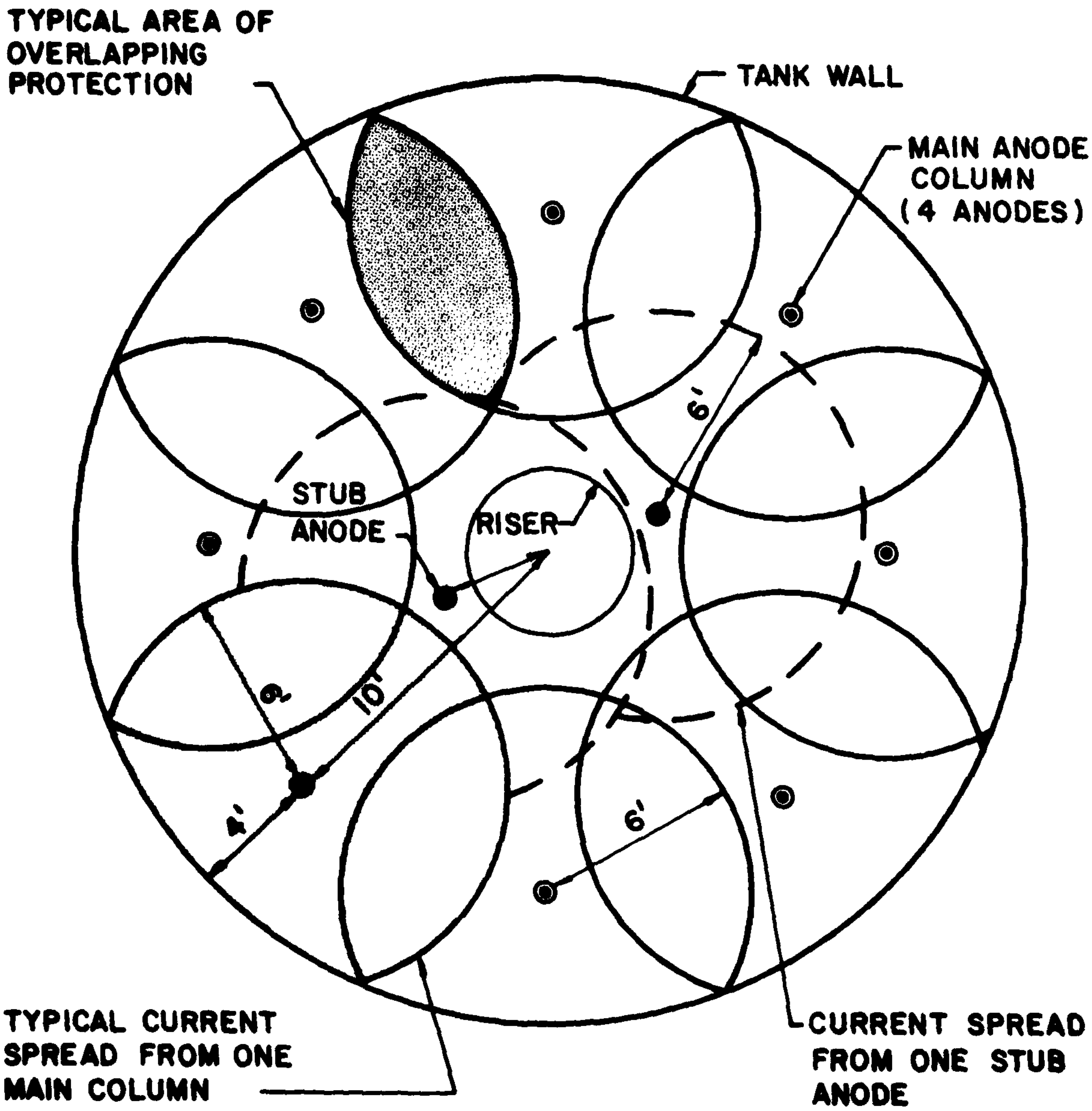

Figure 5. Top View of 100,000-Gallon Water Storage Tank at Selfridge Air National Guard Base Showing the Location of Anode Columns for the Cathodic Protection System

SECTION IV

INSTALLATION OF THE ACTUAL SYSTEM

Fabrication of the Anode Columns

The main anode and stub-type anode columns were prefabricated from 4-inch x 4-inch x 0.25-inch (square tube) polyester-type, fiberglass (EXTREN 500®) using lengths which would satisfy the anode locations identified during the design phase. The button-type K-6 anodes were sealed on their back faces using EPI-Seal, Spec 10-10 adhesive and bolted in place. A pre-cut, No. 8/7-strand copper, HMPE header cable was introduced into each column through the connector insert located near the base of the column, electrically connected to the anode studs, and bolted in place. SCOTCH-Cast Epoxy® was used to isolate the bare metals inside the columns from the environment. All of the access holes and other openings in the columns were subsequently sealed using polyester-type fiberglass and/or EPI-Seal, Spec 10-10.

Square-shaped, steel base supports were designed and prefabricated in order to hold the anode columns upright in the tank. The lengths of the two legs on each support were adjusted to fit the curvature of the tank bottom in order to facilitate welding. The columns were inserted into the base supports and bolted in place. The assembled, main anode columns attached to their base support are shown in Figure 6.

The slenderness ratio of the assembled columns suggested that horizontal supports between the columns and the tank wall would be required in order to provide adequate structural integrity inside the tank. Provision for this was accomplished by fabricating steel support brackets which could be welded to the tank wall. Basically, the steel support bracket consisted of two short-length 2.5-inch by 2.5-inch by 0.25-inch steel angles which were welded (4 inches apart) normal to a steel base plate. With these support brackets welded to the tank wall, 2-inch by 2-inch by 0.25-inch, polyester-type, fiberglass angles could be rigidly anchored (bolted) between the support brckets and the main anode columns. It was decided that three horizontal supports would be required for each main column. These should be located approximately 5, 7, and 9 feet above the tank bottom.

Installation

When the tank was drained, cleaned, and readied for installation of the anode system, it was found that the four-coat, high-build vinyl coating system was in relatively good condition. The coating efficiency was certainly greater than 50

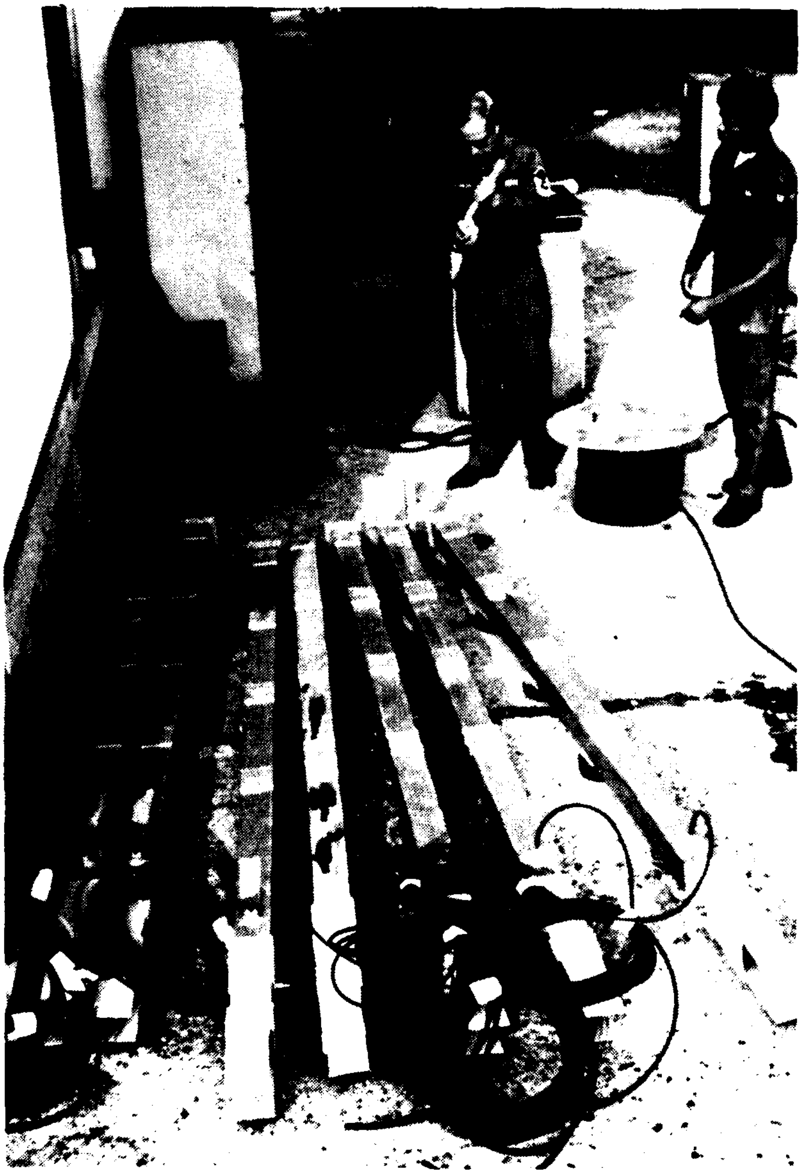

Figure 6. Assembled Main Anode Columns With Steel Base Supports Attached

percent; this made the cathodic protection design even more conservative than had been anticipated. This is mentioned only to emphasize that properly specified and applied organic coatings can be used to protect a significant portion of a water-tank interior; cathodic protection is only required to protect the uncoated steel at holidays (defects) which exist in essentially all coatings. The synergistic effect of coatings combined with cathodic protection significantly reduced the current required for protection and insures adequate protection throughout the tank.

The base support for the main anode and stub-type anode columns were readily welded to the tank bottom in their respective positions (Figure 4 and 5). Subsequently, the three horizontal support brackets for each main anode column were welded to the tank wall. The polyester-type, fiberglass horizontal supports/angles were bolted to the steel brackets; the horizontal supports were both adhesively bonded to the main columns using EPI-Seal, Spec 10-10, and bolted to hold the supports in place during the curing cycle for the adhesive.

The long-length header cables (one to each column) were held in place and protected from damage by locating them inside polyvinyl chloride (PVC) conduit which was anchored to the columns and around the tank bottom using pre-shaped steel straps (Figure 7). Concurrently, three permanent copper-copper sulfate reference cells were positioned inside the bowl in order to monitor the tank-to-water potentials on a continuing basis without necessitating the need to climb the tank (Figure 8). A fourth permanent reference electrode was included to determine the potential in the riser. The location of these electrodes with respect to the anode columns is shown in Figure 9. The three reference electrodes in the bowl were positioned such that they would measure relatively bare areas of steel where the least amount of cathodic protection would be expected to occur. If the potentials at these three locations revealed that adequate protection had been achieved by the cathodic current, it was reasonable to believe that the entire tank was protected. The permanent reference electrodes were held in position (approximately 0.75 inch from the tank) using steel straps welded to the tank. PVC conduit was used to protect the lead wires to the reference electrodes.

The anode header cables and reference electrode leads were collected and exited from the tank at the top. This was accomplished by placing the cables in two PVC conduits which were strapped in place up the tank wall (Figure 10). Each of the continuous cables and leads terminated at a watertight junction box located on (outside) the roof of the tank. From the junction box to ground level, the header cables and lead wires were protected by placing them inside a 2-inch-diameter flexible PVC conduit which was anchored to a support leg of the tank.

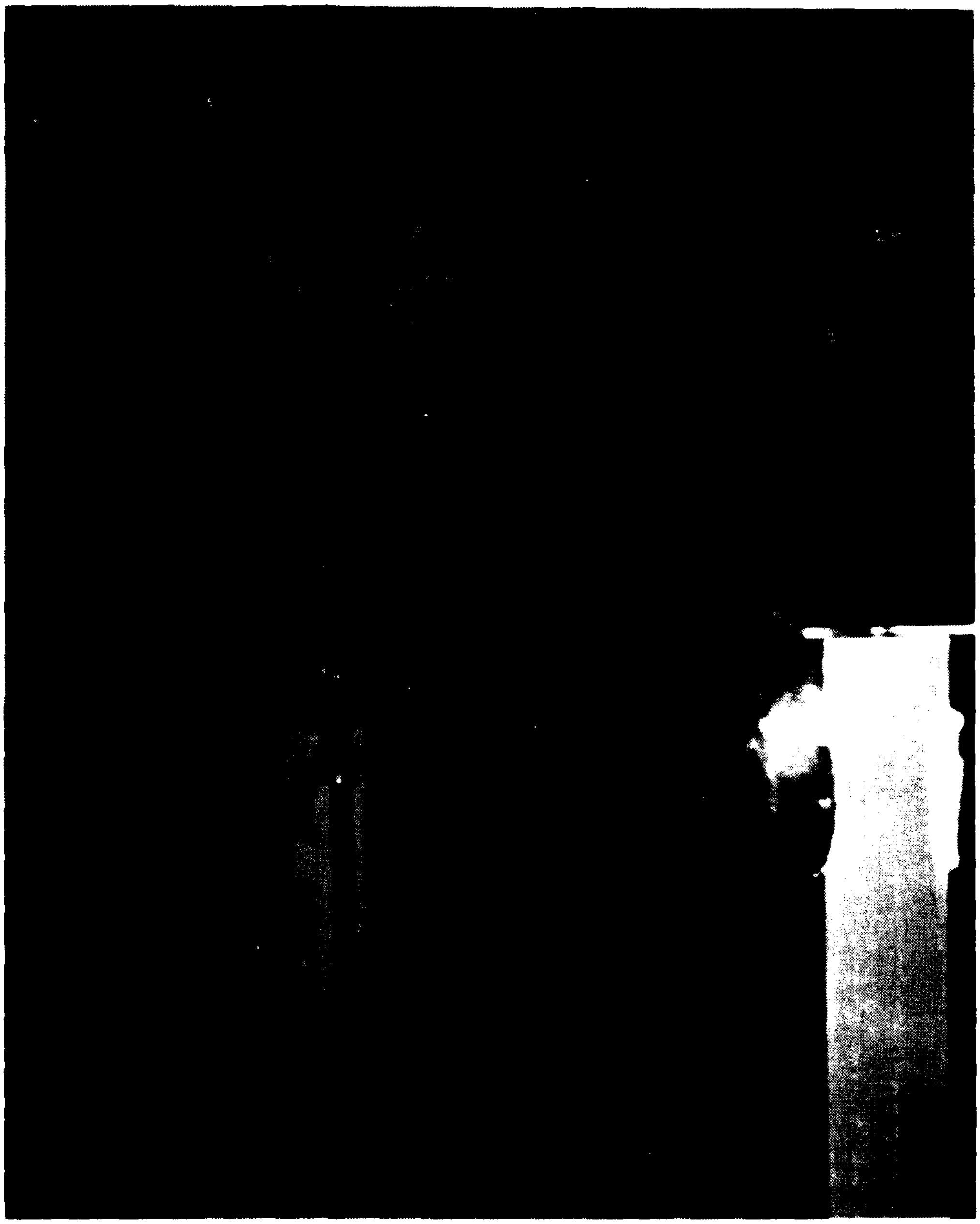

Figure 7. Main Anode and Stub-Type Anode Columns Inside Water Storage Tank. The Header Cable for Each Column Was Held in Place and Protected Using PVC Conduits; the Conduit Was Anchored, Using Steel Straps Welded to the Columns and the Tank Bottom.

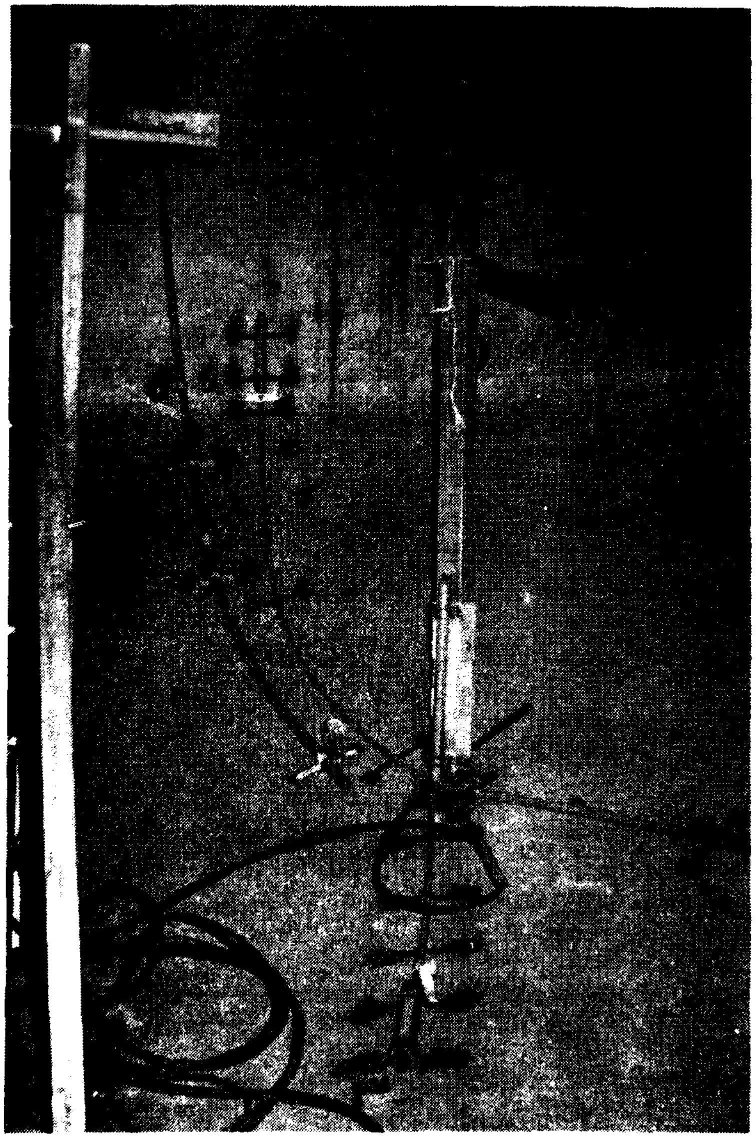

Figure 8. Three Permanently Installed Copper - Copper Sulfate Reference Electrodes Were Used to Monitor the Tank-to-Water Potential Inside the Bowl

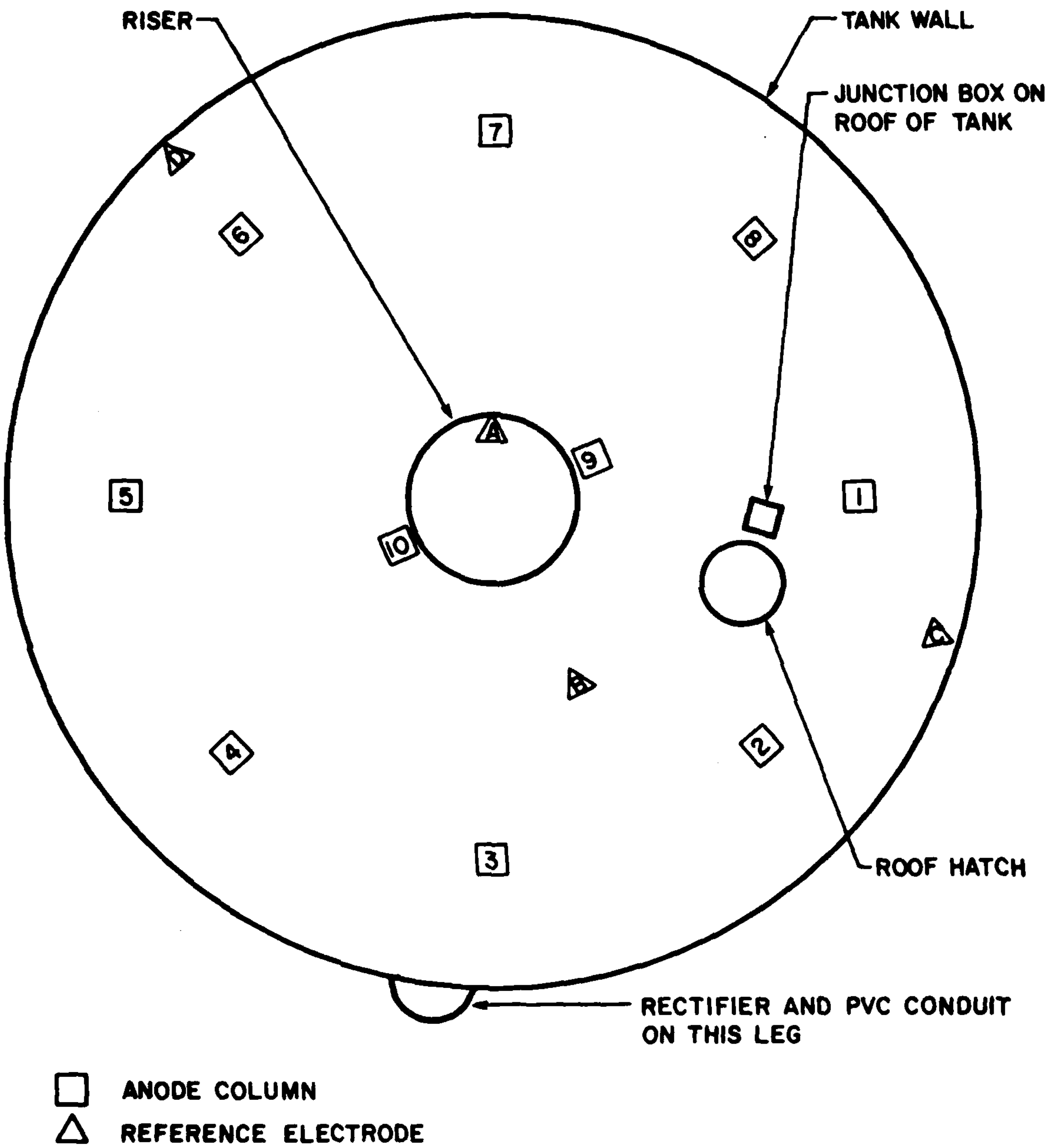

Figure 9. Location of Reference Electrodes With Respect to Anode Columns

Figure 10. The Anode Header Cables and Reference Electrode Leads Were Exited From the Tank Using Two PVC Conduits Strapped to the Tank Walls

The header cables for the eight main anode columns terminated at individual terminals inside a test station at ground level (at the left in Figure 11). The header cable for both stub-type anode columns terminated at one terminal inside the same test station (bottom terminal in Figure 11). Each of these terminals was connected to a common bus bar through 0.01 ohm shunts. Unsing the 9-pole selector switch and ammeter provided in the test station, it was possible to measure the anodic current output of each main anode column and the two stub-type anodes. These currents could also be checked by measuring the IR drops across the 0.01 ohm shunts and applying Ohm's Law (i.e., I = E/R where E is in millivolts and I is in milliamperes). The bus bar was connected to the positive terminal of the rectifier.

The four reference electrode leads also terminated at individual terminals inside the test station (lower left in Figure 11). Tank-to-water potentials could be measured at ground level by connecting the positive lead of a high impedance volt meter to each terminal with the negative lead of the voltmeter connected to the negative terminal of the rectifier.

Activation of the System

The cathodic protection for protecting the bowl of the tank was energized on 25 June 1976. Tank-to-water potentials revealed that the bowl could be adequately protected at a rectifier output of 2 amperes at 6.5 volts. Measurements revealed that the current output from each of the main anode columns was nearly identical (about 0.2 ampere); the current output from the two stub-type anodes was approximately 0.12 ampere. The tank-to-water potentials at the three locations inside the bowl varied from -0.92 to -1.33 volts (i.e., actually somewhat more negative than the -0.85 volt, current-on criteria selected for protection).

Although the bowl was adequately protected, there was no protection at this time to the riser. Delivery schedules and technical problems at the manufacturer prevented the anode assembly for the riser from being installed until 29 September 1977.

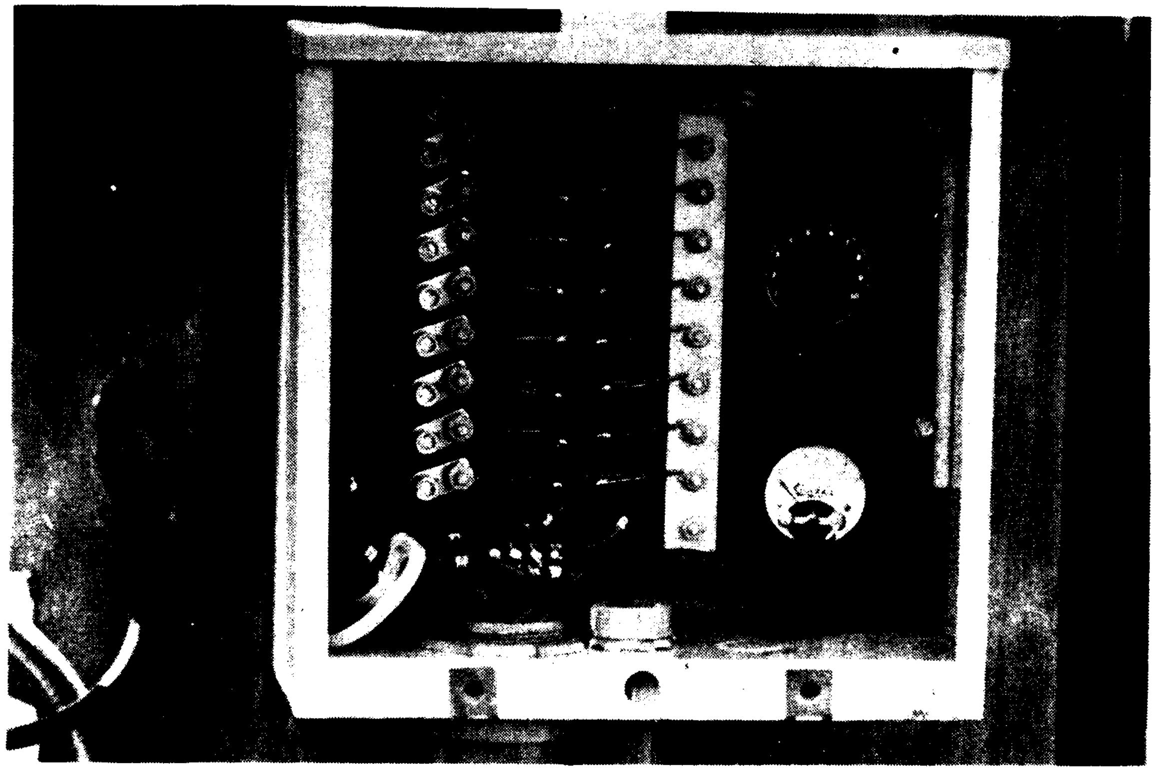

Figure 11. Test Station for Monitoring Current Outputs of Main Anode Columns and Combined Stub-Type Anode Columns. Provisions Included Measuring the Tank-to-Water Potentials at Ground Level.

SECTION V

OPERATIONAL HISTORY OF THE SYSTEM

Initial Operation

Between 25 June 1976 when the system designed to protect the bowl of the tank was first energized and 18 October 1976, it was observed that the current required for protection decreased from about 2 to 1.5 amperes and the output voltage of the rectifier increased from 6.5 to 8.5 volts. This revealed that the system was functioning properly and desirable polarization of the steel was taking place. During these four months, the tank-to-water potentials at all three reference electrodes shifted further in the negative direction approximately another 0.35 volt. The system was also functioning satisfactorily on 28 December 1976.

The first indication of any trouble with the system occurred in April 1977 when Selfridge ANGB personnel reported that the current output from one of the main anode columns was zero. They suspected that some damage to the column may have occurred during the April thaw at a time period when there was an unusually heavy demand for water from the tank. Their concern was based upon knowledge that as much as 30 inches of ice may have formed around the wall of the tank during the unusually severe winter. Unfortunately, the tank could not be emptied for assessment of any damage.

The first opportunity to inspect the interior of the tank was in September 1977 when it was scheduled to add the anode assembly for protecting the riser.

Inspection of the Tank - September 1976

Inspection of the tank interior on 27 September 1977 revealed that significant damage had occurred only to five of the main anode columns. These had fractured near the steel base supports used to hold them upright. The main anode columns which remained vertical were No. 1, No. 4, and No. 8 (see Figure 9 for column location). It was also noted that all 48 of the horizontal supports for the main anode columns had fractured at locations hear the steel support brackets on the tank wall (Figure 12).

Further examination of the damage revealed that several of the steel support brackets on the wall had been severely deformed; similar damage had occurred to several of the steel base supports for the main anode columns. The lead wire (i.e., the header cable near the column) to column No. 2 was severed, and the insulation on the lead wire to column No. 7 was damaged.

Figure 12. All of the Horizontal Support and Five of the Main Anode Columns Were Fractured During the Severe Icing Conditions Which Occurred During the 1976-1977 Winter

No damage had occurred to the two stub-type anode columns, the reference-cell assemblies, or the header cables located along the bottom and wall of the tank.

The damage assessment suggested that the horizontal supports were primarily responsible for the fracture of the five main anode columns. Ice formation and possibly falling ice during the heavy demand for water during the April thaw caused failure of the horizontal brackets at the tank wall which subsequently produced unacceptable bending-moment stresses on the non-metallic columns at the restrained steel, base supports.

Reactivation of the System

Since it was believed that the cathodic protection system had been sufficiently overdesigned, the decision was made to reenergize the undamaged anodes. Only the anodes on columns No. 2 (severed lead wire), No. 7 (damaged insulation on lead wire), and No. 5 (fracture resulted in anodes being located too close to the tank bottom) were disconnected. Fortunately, the three remaining anode columns were located between those which had to be disconnected (Figure 9), and two of the fractured main columns still had their anodes approximately 3 feet above the tank bottom.

The anode assembly for protecting the riser was installed, and the system was reenergized on 29 September 1977. Two days later, at a rectifier current output of 1.2 amperes (8.5 volts) to the bowl, adequate protection was obtained. The permanent reference electrode potentials in the bowl varied from -1.02 to -1.34 volts. This small amount of over-protection in the bowl was necessary in order to adequately protect the riser.* These results clearly demonstrate the advantage of the quality coating which existed inside the tank. If the tank had been poorly coated, it would have been impossible to protect the bare steel using the anodes which remained.

Although protection for the tank bowl was an important consideration, the experiment was continued primarily to determine if any additional damage would occur to the three main anode columns (i.e., columns No. 1, 4 and 8) which were not fractured and were still vertical. This hopefully would provide insight regarding the need for horizontal supports.

Inspection of the Tank - July 1978

Inspection of the tank interior on 15 July 1978 revealed that no additional damage had occurred to columns No. 1, 4, and 8 (i.e., the main anode columns which remained vertical). There

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*The riser was adequately protected by 0.4 ampere of cathodic current.

was also no damage to the stub-type anode columns (Figure 13). The reference electrode assemblies and the header cables along the floor and wall of the tank were intact. The only additional damage observed was to column No. 3 which was already fractured; it now rested on the bottom of the tank.

These results were considered to be significant since the 1977-1978 winter at Selfridge ANGB was approximately 20 percent more severe than normal.

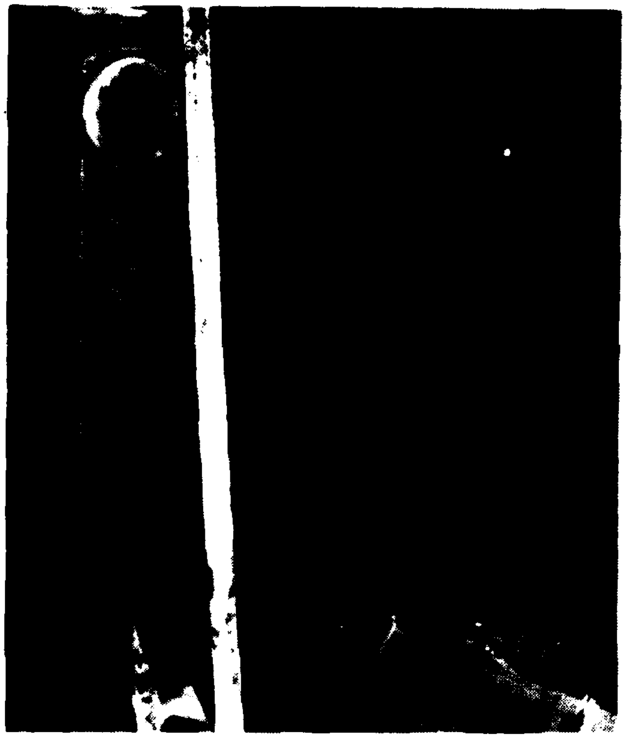

Figure 13. There Was No Additional Damage to the Anode System During the Severe Icing Conditions Which Occurred During the 1977-1978 Winter

CONCLUSIONS

Based upon the results obtained during this investigation, it can be concluded:

1. Bottom-supported anode assemblies can be effectively used for impressed-current type cathodic protection systems in water-storage tanks.

2. Button-type high-silicon chromium-bearing cast iron anodes can be used to effectively protect the bowl areas of water-storage tanks.

3. Semi-rigid columns used in the installation of a bottom-supported anode, cathodic protection systems should not be connected to the tank wall with horizontal supports in geographical areas of severe or mild-to-severe icing conditions.

4. Anode header cables and reference electrode assemblies can be subjected to severe icing conditions without damage providing they are properly anchored to the tank wall/bottom.

5. Anode placement/location is not significantly important in reasonably well-coated water-storage tanks.

6. Relatively lightweight vertical columns for bottom-supported anode assemblies can be readily fabricated from polyester-type fiberglass shapes.

RECOMMENDATION

A bottom-supported anode system for an impressed-current type cathodic protection should be designed and installed using the recently available platinum-coated, niobium (columbian)/titanium wire for the anode material. The wire could be adapted to an extremely slender and flexible support column.

REFERENCES

1. Air Force Manual AFM 88-9, Chapter 4, "Corrosion Control", pp. 262-289, 1 August 1962.

2. "Cathodic Protection for Corrosion Control in Water Works Equipment," Harco Corp., Medina, Ohio, circa 1974.

APPENDIX A

DESIGN CALCULATIONS FOR AN ACTUAL SYSTEM

Introduction

The cathodic protection system for the 100,000-gallon double-ellipsoidal, steel water storage tank at Selfridge ANGB, Michigan, was basically designed using information presented in AFM 88-9, Chapter 4, "Corrosion Control", pp. 262-289. The design was based upon: (1) a 10-year life expectancy for the cathodic protection system; (2) a current density requirement of 5 ma/ft^2 of uncoated steel; (3) a 50-percent coating efficiency; (4) a water resistivity of 5,000 ohm-cm; (5) an anode deterioration rate of 1 lb/amp-yr; and (6) a 50-percent anode efficiency.

The design included seven basic steps: (1) calculation of the wetted surface area inside the tank; (2) calculation of the maximum design currents required for protection; (3) calculation of the minimum anode weight required to achieve the 10-year design life; (4) selecting an anode for the riser; (5) determining the radius of the main anode circle around the tank bowl; (6) establishing the circumferential spacing for the main anode assemblies; and (7) selecting the main anodes for the tank bowl.

Surface Area Calculations

1. Wetted surface area of the tank bowl (A_B)

$$A_B = A_{TOP} + A_{CENTER} + A_{BOTTOM} = 2\pi rx + 2\pi rh + \sqrt{2}\,\pi r\sqrt{a^2 + r^2}$$

where

r = radius of tank in feet (14 ft)

x = height of the wetted surface in the top section (5 ft)

a = minor axis of bottom-section ellipse (7 ft)

h = height of vertical wall (14 ft)

$$A_B = 2\pi(14)(5) + 2\pi(14)(14) + \sqrt{2}\,\pi(14)\sqrt{(7)^2 + (14)^2}$$

$$= 439.8 + 1231.5 + 973.6$$

$$= 2645 \text{ ft}^2$$

2. Wetted Surface Area of the Riser (A_R)

$A_R = 2\pi rh$

where

r = radius of the riser (2.5 ft)

h = height of the riser (96.5 ft)

$A_R = 2\pi\ (2.5)\ (91.5)$

$= 1437\ ft^2$

MAXIMUM DESIGN CURRENTS REQUIRED

1. Bowl Current (I_B)

$I_B = (i_{req})(A_B)(E)$

where

i_{req} = current required to protect each square foot of bare steel (5 ma/ft^2)

E = coating efficiency (0.5)

$I_B = (5)(2645)(0.5)$

$= 6610$ ma

$= 6.61$ amp

2. Riser Current (I_R)

$I_R = (i_{req})(A_R)(E)$

$= (5)(1437)(0.5)$

$= 3590$ ma

$= 3.59$ amp

MINIMUM ANODE WEIGHT REQUIRED

1. Bowl Anodes Weight (W_B)

$W_B = YSI_B/E$

where

Y = design life expectancy (10 years)

S = anode deterioration rate (1 lb/amp-yr)

E = anode efficiency (0.5)

$W_B = (10)(1)(6.61)/0.5$

$= 132$ lbs

2. Riser Anode Weight (W_R)

$W_R = YSI_R/E$

$= (10)(1)(3.59)/0.5$

$= 71.8$ lbs

SELECTION OF RISER ANODE

Two high-silicon chromium-bearing cast iron (HSCBCI) anodes which are commercially available on flexible cables were considered (Durco Type FW and Durco Type G-2). Durco Type FW anode is 9 inches long, 1.13 inches in diameter, weighs one pound, and has a maximum current discharge of 0.025 ampere. This anode was readily eliminated from consideration since the number (length) of anodes required to satisfy the maximum current discharge limitation would exceed the height of the riser (i.e., (3.59/0.025) (0.75) = 108 ft).

Using similar calculations and allowing for protection of the ladder inside the riser, it can be shown that 39 Durco Type G-2 anodes (9 inches long, 2 inches in diameter, 5 pounds in weight, and having a maximum current discharge rate of 0.1 ampere) would be required. The weight of these 39 anodes is 195 pounds which more than satisfies the 10-year life expectancy for the system.

The total weight of the Durco Type G-2 anodes and the header cable (based upon No. 4 - 7 strand copper, HMPE-insulated header cable) would be 211.6 pounds which is sufficiently less than the 1320-pound breaking strength of the No. 4 cable. Durco Type G-2 anodes and No. 4 header cable were therefore selected for the riser-anode assembly/string.

RADIUS OF THE MAIN ANODE CIRCLE AROUND THE TANK BOWL

$R = DN/2(\pi + N)$

where

R = Radius of the main anode circle (ft)

D = diameter of tank in the center section (28 ft)

N = number of anode columns (8)

$R = (28)(8)/2(\pi + 8)$

$= 10$ ft

SPACING FOR MAIN ANODE ASSEMBLIES

1. Circumferential Spacing (C)

$C = 2\pi R/N$

$= 2\pi(10)/8$

$= 7.85$ Ft

2. Cord Spacing (1)

Based upon the use of eight main anode columns, they would be located every 45° around the tank bottom.

$1 = 2R \sin 22.5°$

$= (2)(10)(0.383)$

$= 7.65$ ft

SELECTION OF MAIN ANODES FOR THE TANK BOWL

Two button-type HSCBCI anodes were considered (Durco-type K-6 and Durco-type K-12). Based upon a maximum current requirement of 6.61 amperes, a minimum anode weight of 132 pounds, and 8 main anode columns, it can be shown that the current discharge from each anode column must be 0.83 ampere (i.e., 6.61/8); the minimum anode weight for each column must be 16.5 pounds in order to achieve the desired 10-year life expectancy (i.e., 132.2/8).

Durco-type K-6 anode is 6 inches in diameter and 2.5 inches thick; it weighs 16 pounds and has a maximum current discharge of 0.225 ampere. In order to achieve a minimum of 0.83 ampere output from one column, it would require four of these anodes (i.e., 0.83/0.225 = 3.7 = 4 anodes

Durco-type K-12 anode is 12 inches in diameter and 3.4 inches thick; it weighs 53 pounds and has a maximum current discharge of 0.8 ampere. One of these anodes would be required for each column.

The smaller, Durco-type K-6 anodes were selected in order to provide a more uniform distribution of the cathodic current around the wall and botrtom of the tank. This is understandable since an anode will protect a length along the bottom and/or wall that is at least 1.5 times the spacing of the anode from the wall and/or bottom. Since each anode is 4 feet from the tank (R = 10 feet, it will protect a minimum of 6 feet of tank wall and/or bottom.

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HQ AFESC/TST	2	AFRCE-ER/S4	2
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HQ ATC/DEMU	2	NGB/ANG/FSC/DE	6
HQ AAC/DEMUC	6	HQ AFCS/DEE	2
HQ MAC/DEMP	6	DDC/DDA	2
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ESC/DEMU	6	AFML/MKP	2
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